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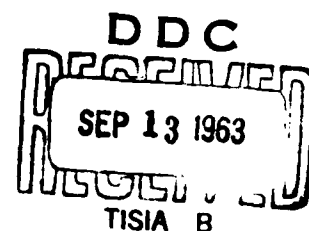CAMERON STATION, ALEXANDRIA, VIRGINIA

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NOLTR 63-12

TWO EXPLOSIVES GENERATING
CONDENSIBLE PRODUCTS

NOL

29 MAY 1963

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 63-12

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Explosives of the type described in this report will be of
interest primarily to research scientists working in the
field. Where allied investigations demand a detonation which
results in completely condensible products, these compositions
offer excellent prospects of providing the required research
tool.

The reported work has generated new data on the reaction
characteristics of what are essentially simple, metal-inorganic
oxidant explosives. The number of experiments was small but
carefully done. Correlations with computer calculations and
experimental work performed in Great Britain lend support to
the validity of the results. The opinions expressed herein
are the author's and do not necessarily reflect those of the
Laboratory.

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                           By direction

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TWO EXPLOSIVES GENERATING CONDENSIBLE PRODUCTS

1. Introduction

1.1 Mixtures of aluminum with several high energy oxidants were studied to establish detonability, detonation velocity, and reaction products. Reaction products were of primary interest to determine whether a detonating charge could be prepared which produced an after-detonation residue consisting only of steam and other condensible species.

The number of charges potentially capable of detonation and of producing water and reaction products largely condensible to solids or liquids is limited. No single explosive compound was known that would fulfill the product requirements. Two steam producing charges were considered in which oxygen produced outside of steam was balanced with aluminum to Al_2O_3. They were lithium perchlorate trihydrate-aluminum and hydrogen peroxide-aluminum. In the initial work with H_2O_2-aluminum, 40 micron amorphous aluminum powder was suspended by gelling 90% hydrogen peroxide with a carboxy polyvinyl chloride. Witness plate perforations indicated that a detonation pressure of 95 kilobars or higher was achieved by this mixture when initiated with 100 gm of tetryl. Though the gels had impact hammer sensitivities well over 150 cm, the gelling agent was an organic fuel contributing to the permanent gas produced by the charge. In addition serious compounding problems were foreseeable in preparing large charges by suspending aluminum powder in gelled H_2O_2. The gelation of hydrogen peroxide as a means of suspending aluminum powder was discontinued, therefore, in favor of injecting H_2O_2 into self-supporting aluminum wool pressed to the required density. It was found in a literature survey [5] that aqueous H_2O_2 in concentrations above 95% can be initiated to decomposition at a stable detonation velocity under proper conditions of boostering, charge diameter and confinement. Because of its importance to the detonation properties of aluminum-hydrogen peroxide mixtures, an experimental and machine calculation study of aq. H_2O_2(98%) was undertaken to confirm this. Results led to the preparation of aluminum-H_2O_2(97-98%) charges with which this report is largely concerned.

2. Lithium Perchlorate Trihydrate-Aluminum Charges

2.1 Lithium perchlorate trihydrate-aluminum charges based on the stoichiometry $3LiClO_4 \cdot 3H_2O + 8Al \longrightarrow 3LiCl + 4Al_2O_3 + 9H_2O$

have a 50% impact initiation height above 320 cm when prepared
with Reynolds No. 400 aluminum powder (weight average diameter
7 microns measured by Micromerograph). Heat of explosion is
2070 cal/g calculated directly from heats of formation.
Charges of lithium perchlorate trihydrate-aluminum with and
without anhydrous lithium perchlorate, Table 1, were initiated
with 100 g of tetryl over quarter-inch thick mild steel plates
which can be perforated by pressures of 95 kbar or higher.

TABLE 1

Aluminum-Lithium Perchlorate

Component	Composition No.								
	1	2	3	4	5	6	7	8	9
$LiClO_4 \cdot 3H_2O$ (%)	69	50	27	0	39	69			
$LiClO_4$(anhyd) (%)		16	36	60	26				
Aluminum (%)	31	34	37	40	35	31	35	32	24
$KClO_4$ (%)							65	59	52
Water (%)								9	24
Charge Wt. (g)	227	227	227	227	454	454	454	454	454
Result in Air[1]	O	O	O	O	P	P	P	O	O

Three compositions, as shown in the table, produced minimum
perforation pressures. Of these, Compositions 5 and 6 were
balanced to LiCl, Al_2O_3 and water; Composition 7 was hydrogen
free and therefore not useful for steam generation.

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(1) O - No plate performation.

P - Plate perforated.

TABLE 2

31% Aluminum - 69% Lithium Perchlorate Trihydrate
Detonation Velocity Measurement

	Confinement		
	Glass	Glass & Steel	Glass & Steel
Detonation Velocity Initial 2.5 cm (m/sec)	3800	2800	2652
Final 2.5 cm (m/sec)	3300	2300	2285
Density (g/cm3)	1.287	1.224	1.211
Charge Diameter (cm)	7.58	7.75	7.75
Steel Wall Thickness (mm)	3	3	3
Glass Wall Thickness (mm)	3	3	3
Charge Length (cm)	20.3	20.3	20.3
Charge Weight (g)	1180	1172	1158
Tetryl Booster (g)	100	100	100

2.2   The higher detonation velocity of the glass confined charge was investigated by a repeat shot since its time-displacement trace showed a continuous drop in velocity over the 20.3 cm charge length. Overboostering occurred in the first 2 cm of the steel confined charges as shown by decay in the reaction rate over this distance. The remainder of the time traces had constant slope. The steel confined charges were therefore in a stable reaction state at a velocity near 2300 m/sec.

2.3   A 400 gm charge of 8 Aluminum-3 $LiClO_4.3H_2O$ (31/69) was boostered with 100 gm of tetryl in an evacuated tank having a volume of 103 liters. The static, after-detonation pressure in the tank was measured and samples were taken of the gas residue. Table 3 presents charge data and results of a mass spectrometer analysis of the residue.

The calculated distribution of reaction products in Table 4 was based on the following considerations:

(1) Excess hydrogen over that left by the detonator and tetryl booster alone is a direct measure of the reduction of steam by aluminum.

(2) Steam formed is indicated by the difference between hydrogen in the charge and moles of excess hydrogen in the residue.

(3) Charge oxygen which oxidizes carbon residues from tetryl can be determined by the difference between CO and CO_2 in the tetryl residue alone and in the residue of charge plus tetryl.

(4) Little or no oxygen liberated by the charge reacts with the tank (4.3.1).

(5) Oxygen not in steam or carbon oxides is in alumina since no oxygen appeared in the residue.

2.4 Though the charge itself was balanced to LiCl, H_2O and Al_2O_3, the total oxygen balance was negative because of carbon and carbon monoxide from tetryl; an additional 9.45 g of oxygen per 100 g of charge were required to oxidize carbon fuels injected by tetryl to CO_2. In the detonation, carbon residues combined with 3.06 moles (89%) of perchlorate oxygen. Perchlorate oxygen remaining after the oxidation of carbon residue did not appear as free oxygen and must have reacted with the only other available fuel, aluminum. This left 4.08 moles (89%) of the aluminum free to reduce steam. Forty-five percent or 1.82 moles of this free aluminum did reduce steam producing 2.73 moles of hydrogen and leaving 2.44 moles of residual steam.

2.5 The significant result of the shot is reduction of 53% of steam from the charge by aluminum. Only half of available free aluminum actually reduced steam so that the aluminum reaction is not quantitative. As the ratio of charge to tetryl increases, in scaling up the charge, the oxygen balance will approach zero with respect to steam and alumina. The single experiment reported here is insufficient for predicting the change in reaction product at oxygen balances above -9.45. There is, however, evidence in the

TABLE 3

31% Aluminum - 69% Lithium Perchlorate Trihydrate

	Charge Data	
Tetryl Booster	101.2 g	.35 moles
Charge Size	400 g	
$LiClO_4 \cdot 3H_2O$	276 g	1.72 moles
Aluminum (a)	124 g	4.60 moles
H_2O in Charge	93 g	5.16 moles
Charge Diameter	74 mm	
Charge Length	69 mm	
Detonator	420 mg tetryl, 324 mg lead azide	

Gas Analysis

	Detonator Tetryl Residue(D) (moles)(b)	Charge Residue(c) (mole %)	Residue Composition (moles) (C)	C-D Differential (moles)
Hydrogen	.95	39.3	3.68	2.73
Nitrogen	.91	9.7	.91	.00
Carbon Dioxide	.19	37.8	3.54	3.35
Carbon Monoxide	1.80	13.1	1.23	(-) .57
Oxygen	.00	.0	.00	.00
	3.85	99.9	9.36	

(a) 7 micron weight average diameter.
(b) Measured in a separate experiment.
(c) For residue from complete charge including detonator and tetryl.
Calculations are discussed after Table 11 and in Appendix B.

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TABLE 4

Gas Residue Analysis for 31% Aluminum - 69% Lithium Perchlorate Trihydrate

Fuel in Charge	(Moles)
Aluminum	4.58
Oxygen Equivalent	3.44
C and CO	2.44
Oxygen Equivalent (to CO_2)	1.48
O_2 Equivalent Total Fuel	4.92
Water in the Charge	5.16
Perchlorate Oxygen in Charge	3.44

Charge Product Analysis	
Hydrogen Produced	2.73
Oxygen in Residue	.00
Distribution of $LiClO_4$ Oxygen in Products	
In CO and CO_2	3.06
In Al_2O_3	.38
Steam Remaining	2.44
Aluminum Oxidation	
By Steam	1.82
By Oxygen Directly	.51
Total	2.33
Aluminum in Charge	4.58
Free Aluminum in Residue (by difference)	2.25
Oxygen Balance of Charge Alone	0.00
Oxygen Balance of Charge with Tetryl and Detonator	-9.45[a]

(a) Grams of oxygen under the CO_2 level per 100 grams of total charge.

experimental work on 2 aluminum - 3 hydrogen peroxide (4.3.3) and in experimental work on water immersed torpexes (4.3.4 and Appendix A) that, in a series of aluminized charges detonating in an aqueous environment and approaching O.B. zero from the negative, (a) the charge oxygen is combined with fuel in the products and does not appear as free gas, (b) aluminum oxidation is complete as O.B. zero is approached (c) hydrogen does not appear in the residue near O.B. zero. In addition Ruby Code calculations (4.3.5) predict complete oxidation of aluminum with less than 5 mole percent of permanent gas species at the Chapman-Jouget state for 2 aluminum-3 hydrogen peroxide.

2.6 The $LiClO_4.3H_2O$ - aluminum reaction is complicated by the presence of lithium and chlorine components in the reacting species. Reaction product equilibria at the C.J. point and after detonation may therefore differ from those of hydrogen peroxide-aluminum and torpexes, depending in large part on the stability of lithium chloride at and after the C.J. state. The amount of lithium chloride in the cold residue is of interest. The solid residue contained 90% of the theoretical yield of lithium chloride. Recovery loss is expected to account for most of the remainder but if all the missing chlorine is present as HCl, the steam yield would be diminished only 1.6%.

Experimental work and calculations cited for torpexes and for 2 Al - $3H_2O_2$ indicate that a large charge of 8 aluminum-$3LiClO_4.3H_2O$ will be an efficient steam generator producing above 90 mole percent of theoretical steam yield.

2.7 The underwater shockwave and bubble properties of an 8-lb charge of aluminum-$LiClO_4.3H_2O$ (31/69) shot at a depth of 25 ft in 40 ft of water were reported in reference (1).

3. Compositions Based on Hydrogen Peroxide and Aluminum

3.1 Mixtures of Amorphous Aluminum Powder with aq H_2O_2 (90%)

3.1.1 Compositions were prepared by gelling 90% aqueous H_2O_2 with 2% by weight of the 75% diethyl aniline salt of carboxy polyvinyl chloride[2] and blending the gel with aluminum powder. Stability of the mixtures was measured by gas evolution since the compatibility of aluminum-H_2O_2 depends on aluminum purity, particularly freedom from copper and lead and the absence of catalytic contaminants. Mixtures with 400 mesh aluminum (50% by weight less than 10 microns) gassed

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little on two days storage. Two gelled charges 35/65 Al/H_2O_2 (90%) produced detonation pressures of 95 kbar or higher when boostered with 100 gm of tetryl. The 35/65 ratio is balanced to water and Al_2O_3.

    3.2 Mixtures of Amorphous Aluminum Powder with aq
          H_2O_2 (98%)

        3.2.1 Consideration was given at this point to the substitution of aq H_2O_2 (98%) in place of the 90% oxidant because of its availability, greater heat of reaction, comparable cost and, as will be discussed later (3.5 and 3.6), its detonability without fuel. Impact hammer sensitivities of a number of mixtures of aq H_2O_2 (97.5%) with aluminum powder are shown in Table 5. Ungelled mixtures of aluminum powder with aq H_2O_2 (97.5%) either 50/50 or 35/65 are considerably less impact sensitive than aq H_2O_2 (97.5%) alone. These mixtures are not homogeneous since without a means of dispersal the aluminum powder settles. The gelled mixtures with aluminum are also considerably less impact hammer sensitive than aqueous H_2O_2 (97.5%), unexpectedly, because the gel is an organic fuel. Some polyvinyl chlorides are relatively compatible with concentrated H_2O_2 and affect the decomposition rate only slightly[3]. Others, depending on entrained additives, are peroxide decomposition catalysts. Standard deviations for both aq H_2O_2 (97.5%) and its mixtures vary somewhat with the state of the samples and cleanliness of the test tools since even dust can increase sensitiveness. Low standard deviations require mixture uniformity. Impact desensitization of H_2O_2 by aluminum powder may be attributable to reinforcement of the alumina film on the powder. Exposure to concentrated H_2O_2 further passivates an aluminum surface[4] which can then act as an inert heat sink, absorbing impact energy.

        3.2.2 Serious technical and safety problems were anticipated in the preparation and assembly of very large charges of gelled aq H_2O_2 containing suspended aluminum powder. Though present in small concentrations, the gelling agent produces permanent gas which, as carbon fuel, affects the reaction equilibrium of aluminum and free (non-steam) oxygen on which performance of the charge as a steam generator with low permanent gas output depends. Also, though some gelling agents have at least temporary stability with concentrated H_2O_2, the possibility of accidental contamination by H_2O_2 decomposition catalysts is increased. Experiments were therefore undertaken in which aluminum in the form of a fine wool was dispersed throughout charges of aq H_2O_2 (97-98%).

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TABLE 5

Impact Sensitiveness of Aluminum H_2O_2 Mixtures

15 Micron Al(c) (Wt. Parts)	Sample H_2O_2 (97.5%) (Wt. Parts)	Gelling Agent(a) (Wt. Parts)	50% Impact Ht. (cm)	σ (b) (log units)	No. of Shots
34.5	65.5	0.0	297	0.18	25
34.5	65.5	2.0	174	0.35	15
0.0	100.0	0.0	97	0.05	25
0.0	100.0	0.0	96	0.18	25
51.4	48.6	0.0	>320	--	25
51.4	48.6	2.0	235	0.30	25
420 Micron Al(c)					
35.0	65.0	0.0	213	0.16	25

(a) 75% Diethylaniline salt of carboxy polyvinyl chloride

(b) Standard deviation

(c) Maximum diameter

3.3 Stability of aq H_2O_2 (98%)

3.3.1 Ninety percent aqueous H_2O_2 is concentrated by fractional crystallization to produce aq H_2O_2 (98%). Crystallization is both a concentration and a purification procedure which removes traces of contamination from the already highly purified 90% concentrated mother liquor. As a result, aq H_2O_2 (98%) is the most pure and stable form of H_2O_2 with an annual decomposition rate at ambient temperature of less than 1%. Between 30 and 100°C the decomposition rate increases by a factor of 2.4 for each 10°C rise and is no greater for samples with low contaminant concentrations[4]. Procedures for handling aq H_2O_2 (98%) are based on isolating it from reducing agents and decomposition catalysts. Its chemical stability in contact with compatible materials at ambient temperatures has been established. Such materials are aluminum, purity 99.6%, perfluoroethylenes, borosilicate glass and mylar. Materials, equipment and methods have been developed for transporting and handling aq H_2O_2 (98%) on a large scale industrially and considerable technical experience is accessible.

3.4 Detonation Properties of aq H_2O_2 (97-98%)

3.4.1 Some prior work has been done[5] on the ability of aq H_2O_2 (96+%) to detonate without fuel under heavy confinement and strong boostering. Since the detonation properties of H_2O_2 will influence the detonability of H_2O_2-aluminum mixtures, the detonation velocity of aq H_2O_2 (97.5%) was measured as part of this study.[a] A smear camera measurement was made under the following conditions. A 1530 g charge, 7.6 cm diameter, 24.0 cm length, was loaded in a glass cylinder (2.5 mm wall) confined by a tightly fitting, mild steel sleeve (3 mm wall). Initiated by 100 g of tetryl, the charge reacted at 6440 m/sec with no measurable drop in velocity over its length. A 2.54 cm thick steel witness plate under the charge was perforated to a diameter about equal that of the charge. The sensitiveness of aq H_2O_2 (97.5%) to shock initiation was measured by the large scale gap test[6]. In this test 230 g of aq H_2O_2 (97.5%) were confined in a steel cylinder of 3.66 cm

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(a) Highly concentrated hydrogen peroxide varies in strength between containers. The actual strength used in each experiment is reported as measured by the refractive index method using an ABBE Precision Refractometer.

I.D., .56 cm wall, and separated from a standard tetryl
donor by a cellulose acetate gap. The cellulose acetate
thickness was varied in successive shots to obtain a 50%
initiation gap. This gap for aq H_2O_2 (97.5%) was 35 cards
or .35 inches and is compared with gap sensitivities of two
explosives and a double base propellant in Table 6.

TABLE 6

A Comparison of the Large Scale Gap Sensitivities
of aq H_2O_2 (97.5%) and Other Energetic Substances

Composition	Density	%TMD	50% Initiation Gap No. of Cards (a)
AHH Propellant	1.60	--	36
aq H_2O_2 (97.5%)	1.44	--	35
TNT (cast)	1.62	98	138
Composition B (cast)	1.70	99	201

The explosive shock sensitivity of well confined aq H_2O_2 (97.5%)
is therefore near that of a double base propellant and
considerably under that of standard explosives.

3.5 Machine Code Calculations of Detonation Properties
of aq H_2O_2 (98%)

3.5.1 The detonation properties of aq H_2O_2 (98%)
were calculated by the Ruby Code. The code predicts nearly
quantitative decomposition to steam and oxygen (Table 7) at a
detonation velocity of 6436 m/sec. This is remarkably close
to the 6440 m/sec velocity measured at this Laboratory and
compares with 6500 m/sec reported by German experimenters(4)
using both photographic and Dautrische methods. The code
calculated detonation pressure, 137.4 kbars, compares with
the $\rho D^2/4$ approximation of 149 kbars. Detonation velocities
calculated by the Ruby Code for Composition B and TNT do not
match the measured values nearly as well. Accuracy of the
calculation for hydrogen peroxide may be explained by the
absence of solid products and the simplicity of H_2O_2
decomposition producing two gaseous species for which heat

(a) 100 Cellulose Acetate Cards to the inch.

capacity data and equations of state are known with some reliability.

3.6 Detonation Velocities of Aluminum - aq H_2O_2 (97%) Mixtures

3.6.1 The detonation velocities of two 35/65 aluminum - aq H_2O_2 (97%) charges were measured, one confined in glass, the other in glass and steel. The charges were prepared by injecting hydrogen peroxide into an evacuated cylinder of pressed aluminum wool having 3 mil filament diameter. A 1750 g charge, 7.4 cm in diameter, 24 cm long, density 1.71 g/cm^3, was loaded in glass and confined in a slip-fitted steel sleeve having a 3 mm wall. A smear camera photographed the reaction front through a vertical line of holes, 2.4 mm diameter, in the sleeve wall. After initiation by 100 g of pentolite, a detonation velocity of 4300 m/sec was obtained without measurable drop over the charge length. As in the aqueous H_2O_2 (97.5%) shot (3.4.1), a 2.54 cm thick witness plate was completely perforated to a diameter slightly larger than the charge diameter. Another charge (density 1.70 g/cm^3) prepared in the same way but confined only in glass gave an initial velocity of 5180 m/sec, decaying to 3670 m/sec at the end of the charge. The rate trace for the glass confined charge dropped continuously toward subsonic; confinement and charge diameter were probably below the minimum for stable detonation.

4. Reaction Product Studies on Aluminum-aq H_2O_2 (97-97.5%) Charges

4.1 General Procedure

4.1.1 Five aluminum-hydrogen peroxide charges were shot in an evacuated tank to measure the permanent pressure rise and analyze the reaction products. The tank, having a 35.6 cm inside diameter, 103 liter capacity, and 10.2 cm walls was equipped with a gas valve and threaded cover. Charges were suspended from the cover which contained an insulated conductor for one lead of an electric detonator. The other lead was grounded to the cover. Shooting was done in a vacuum of 2.54 mm mercury to keep atmospheric oxygen out of the reaction and to obtain a high partial pressure for each gaseous residue. With one exception charges were initiated by 100 gm of tetryl

TABLE 7

Ruby Code Computation of Detonation
Properties of aq H_2O_2 (98%)

Detonation Velocity (m/sec)	6436
C.J.[a] Temperature ($^{\circ}$K)	701
Charge Density (g/cm^3)	1.442
C.J. Density (g/cm^3)	1.870
C.J. Pressure (kbars)	137.4
Volume of Product Gas at Detonation Pressure (cc/mol)	12.05
Effective γ [b]	3.346
E - Eo (cal/g)	+262

Eo = Energy of unreacted explosive

E = C.J. Energy of explosive

Detonation Energy, ΔE, (cal/gm)   -333

(a) Chapman-Jouget

(b) Constant obtained from $\dfrac{\rho_O}{\rho_{CJ}} = \dfrac{\gamma}{\gamma-1}$ (not C_P/C_V)

where ρ_O = density of unreacted explosive

ρ_{CJ} = density at C.J. pressure

Effective γ is used in the polytropic equation of state,

$E = \dfrac{PV}{\gamma-1}$ and is valid for pressures near the C.J.

pressure.

supported by aluminum tape coated with adhesive. A No. 8
blasting cap containing 421 mg of tetryl and 324 mg of lead
azide was mounted against the tetryl. The booster package,
wrapped in aluminum foil, was positioned on the surface of the
charge which was then suspended from the lid by aluminum wire
and dropped in the tank. After the charge was fired and the
temperature had come to equilibrium, an aneroid absolute
pressure gauge was used to measure the permanent pressure level
in the tank. Evacuated sample tubes were then filled with the
residue gas for analysis by mass spectrometer.

4.2 Charge Preparation

4.2.1 The charge holders were glass cylinders, 73
to 74 mm I.D., 15 cm long, 2.5 to 3 mm wall. Aluminum wools
having filament diameters of 1.5 and 3.0 mils were used.
Corresponding specific surfaces were 386 and 193 cm^2/g
(calculated). The wool was pressed to the required diameter
and height in a separate mold and transferred to the holder.
Some over-pressing was necessary to account for resiliency of
the wool which increased pellet volume after pressing.
Homogeneity of the final charge, an important performance
parameter, depended in large part on the pressing operation.
To avoid large variations in density, the wool was pressed
slowly in two stages to the final volume. The problem of
pressing aluminum filament may be avoided in a large charge
by the use of aluminum needles of a length and diameter having
the required packing density. A study of the performance of
charges prepared in this way is suggested if scaling studies
are undertaken.

4.2.2 Hydrogen peroxide was injected by evacuating
the wool to 2.5 mm mercury and dropping the entire H_2O_2 charge
on the wool surface under vacuum. Air slowly valved over the
H_2O_2 then effectively forced it into the wool until completely
contained.

4.3 Results and Discussion

4.3.1 As foreseen, carbon and carbon monoxide
injected by tetryl considerably complicated interpretation
of results. Free oxygen from detonating hydrogen peroxide
distributed itself between carbon oxides and aluminum (Tables
9 and 10) leaving varying amounts of uncombined aluminum
depending on the oxygen balance. Free oxygen always reacted
completely with available fuel which was in excess in all
charges because total O.B.'s were negative.

An experiment was conducted to determine the extent of oxygen loss to the detonation tank itself for a detonating charge having a large positive oxygen balance, 36.8 grams of oxygen per 100 grams of charge including aluminum, hydrogen peroxide and tetryl. The amount of oxygen unaccounted for in the gas residue was .14 moles or 4% of the oxygen released by H_2O_2 decomposition. This is outside the expected analytical error and indicates the possibility of some oxygen present in a condensed product. The fate of oxygen released by hydrogen peroxide decomposition can be summarized:

In CO_2	38.2% (molar)
Free oxygen	44.0
Reaction with tetryl hydrogen	13.7
Metal oxide	4.1
	100.0

Though it was not possible to recover the solid residue quantitatively for analysis, it is more probable that the small amount of oxygen in condensed products is accounted for by oxidation of 25% of the aluminum surrounding the charge than by reaction with the steel tank. All other charges shot in this study had negative oxygen balances and their residues contained no free oxygen. The probability of appreciable reaction of these charges with the tank is small.

The tetryl residue was also checked because of the importance of knowing its composition and assuring it was consistent. Mass spectrometer analyses of gas products from two charges (Table 12) shows that carbon oxide residues agree within 0.3%; the hydrogen residue varied 2.7%. Accuracy of the analysis itself is + 1% so that true variation in hydrogen concentration may be 1.7 to 3.5% on the basis of the two charges.

4.3.2 Charge B27/73, Table 10, having aluminum filament with twice the surface area of the filament in A27/73, left no hydrogen compared with .15 moles of hydrogen for A27/73. These charges differ only slightly in oxygen balance. Further experiments are necessary to permit a conclusion about the relation of aluminum surface area to steam reduction but within the parameter limits of these experiments fuel surface does not have a predominant effect. Charge 30/70 with a 193 cm^2/g surface area like A27/73 produced a hydrogen residue following the order of oxygen balance of the charges studied (Table 8).

4.3.3 Charge and gas residue data in Tables 13 through 17 were analyzed and the results appear in Tables 9 and 10 which summarize fuel, oxidant and product concentrations. Table 8 is a tabulation of gas residues, oxygen balances and aluminum reactions for all aluminum-hydrogen peroxide charges shot in the product study. As noted in Table 8 oxygen balances to CO_2 were calculated for the complete charges including tetryl booster and detonator since no coherent account of the data is possible without considering all the fuel present. A relation was sought between aluminum oxidation a) by oxygen directly or b) by steam and c) the total oxygen balance (O.B.). At the highest O.B., -5.0, only 0.3% of the aluminum reacted with steam. At lower O.B.'s the aluminum-steam reaction increases until at O.B. -16.6, 30% of the charge aluminum reacted with steam. The direct reaction of aluminum with oxygen approaches 90% at O.B.'s near -5 and drops to below 60% at O.B. -16.6. Steam reduction in these charges can be controlled by varying the oxygen balance. Prediction of the products of a large charge is based on the reaction of all oxygen freed by H_2O_2 decomposition with available fuel. Oxygen was not found in the residues of any of the five aluminum-hydrogen peroxide charges shot in this series. At stoichiometric or zero oxygen balance to Al_2O_3 and H_2O, the concentration of residue hydrogen should be below .005 moles/ 100 g of charge as shown in Figure 1.

4.3.4 Appendix A summarizes the results of experiments[7] with confined mixtures of aluminum in a matrix of 1 to 1 RDX-TNT submerged in water. Aluminum concentrations were varied from 0 to above 50% corresponding to oxygen balances between -12 and -50[a]. Aluminum was competing for oxygen with an organic fuel-oxidant system which, without the aluminum, was below the CO level by 12 grams of oxygen per 100 grams of charge. Aluminum was completely oxidized by the matrix at O.B.'s between -12 and -24. The O.B. had to be below -24 to yield residual free aluminum, and below -32 to start reduction of environmental water. In the entire series of charges consisting of O.B.'s from -12 to -51, free oxygen never appeared in the reaction products.

Aluminum-hydrogen peroxide stoichiometric to water and alumina is a mixture of aluminum dispersed in an H_2O_2 matrix at O.B. zero for the designated products. In a large charge with negligible carbon fuel concentration from an organic booster, oxygen and steam will compete for aluminum
----
(a) To CO and Al_2O_3

TABLE 8

Permanent Gas Residues Produced by Aluminum-Hydrogen Peroxide Charges

Charge	B(27/73)	A(27/73)	(30/70)	(35/65)	(38/62)
1. Oxygen in residue	.00	.00	.00	.00	.00
2. Hydrogen in residue(a)	.005	.04	.27	.30	.47
3. Oxygen balance to CO_2(b)	-5.0	-5.5	-9.0	-11.5	-16.6
4. Free Al in residue (%)(c)	11.0	5.7	0.0	6.5	11.0
5. Al reacting with steam (%)(c)	0.3	3.6	23.0	19.8	30.0
6. Al reacting with oxygen directly (%)(c)	88.7	91.0	76.0	73.5	59.0
7. Product steam (moles)	6.86	6.23	4.65	3.98	3.49
8. H_2/product steam (mole %)	.37	2.4	20.8	24.1	50.5

(a) Moles/100 g of total charge including detonator and tetryl.
(b) Oxygen balance, grams per 100 grams total charge including detonator and tetryl, CO_2 level.
(c) As percentage of total aluminum in the charge (calculated).

under conditions analogous to torpexes with O.B.'s well above -12 where in torpexes a) aluminum was completely oxidized by the matrix and b) environmental water was not reduced.

The charges studied at this Laboratory were shot unconfined so that the potential effect of confinement on the results is of interest. Springall and Roberts[8] postulated that

$$2CO \longrightarrow CO_2 + C$$

$$CO + H_2 \longrightarrow H_2O + C$$
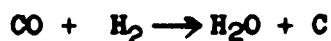
are the probable principal reactions during expansion of the products from an organic explosive. Sexton[7] points out that these reactions are influenced by temperature and pressure and are catalyzed by increasing confinement. This is substantiated in part by Sexton's work[9] with RDX/TNT compositions containing paraffin wax. Wax carbon is oxidized and hydrogen appears uncombined in the products of unconfined charges. In confined charges carbon comes out as soot and hydrogen appears in water, methane and ammonia. Confinement therefore catalyzes the oxidation of hydrogen at the expense of carbon oxides and in the charge residues treated here may be expected to decrease free hydrogen. Confinement should therefore not alter the trend observed in these tests that free hydrogen in the residue diminishes as the oxygen balance rises toward zero.

4.3.5 Ruby Code calculations of the reaction products for $2Al-3H_2O_2$ (98%) indicated that the reaction would involve the conversion of aluminum to liquid alumina. An estimated equation of state for liquid alumina was used in the calculation of gaseous and condensed products at the Chapman Jouget point. The gas products in percentages of the total gas produced were calculated as follows:

	Mole (%)	Weight (%)
H_2O	95.50	99.10
H_2	4.10	.47
OH	.14	.14
O_2	.14	.26
H	.08	.00
O	.04	.03
	100.00	100.00

(a) To CO and Al_2O_3

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Other product species considered by the code were Al_2O, Al_2O_2, AlH, AlO and uncombined aluminum. The concentration of free aluminum was calculated to be zero. Total concentrations of these species was predicted to be well under .001% (molar) of total products.

This calculated composition therefore supports the experimental evidence in predicting that the predominant gaseous product will be steam with only small concentrations of other gaseous species. These gaseous products are predicted at the detonation pressure, calculated as 190 kbar. For condensing products the Ruby Code predicts 25 mole percent Al_2O_3 equivalent to nearly complete oxidation of aluminum to alumina. In the absence of a reducing agent, post-detonation reactions should be in the direction of maximum H_2O concentration.

5.   Summary and Conclusions

5.1   Mixtures of 8 aluminum and 3 $LiClO_4 \cdot 3H_2O$ (31/69) prepared with 7 micron WAD(a) aluminum powder performed in the following manner:

(a)   The 50% initiation height determined by the NOL impact machine was over 320 cm.

(b)   A non-decaying detonation velocity of 2300 m/sec was recorded for a 7.6 cm diameter, well confined charge.

(c)   When initiated with tetryl (400 g charge to 100 g tetryl) one-half the aluminum reduced steam. A charge very large with respect to the organic explosive booster, is predicted to produce near theoretical yields of steam in the post-detonation product equilibrium.

5.2   The impact hammer sensitivity of aq H_2O_2 (97.5%) is 97 cm. Mixtures of aluminum powder and aq H_2O_2 (97.5%) are appreciably less sensitive to the impact hammer than the oxidant itself. Aqueous H_2O_2 (97.5%) has a 50% initiation gap of 35 cellulose acetate cards (.35 inch) in the large scale gap test. A 7.6 cm diameter, well confined charge of

----

(a)   Weight average diameter.

aq H_2O_2 (97.5%) detonated at a stable velocity of 6440 m/sec.
The Ruby Code calculates a detonation velocity of 6436 m/sec
and a detonation pressure of 137.4 kbars for aq H_2O_2 (98%).
A 35/65 mixture of aluminum wool (3 mil filament) and aq H_2O_2
(97%) detonated at a stable velocity of 4300 m/sec in a
7.6 cm diameter, well confined charge.

5.3   Analysis of the reaction products of a series of
aluminum-hydrogen peroxide aq H_2O_2 (97%) charges boostered
by tetryl demonstrated that hydrogen diminishes as the
oxygen balance increases and becomes negligible (.4 mole
percent of the steam produced) at O.B. -5.0 g O_2/100 g charge.
Comparable results were obtained in a study of the reaction
products of confined torpexes immersed in water reported in
reference (7).   At higher oxygen balances (-12 to -24 g
O_2/100 g charge) aluminum was completely oxidized without
reduction of ambient steam.   Ambient steam was not reduced
until the O.B. dropped below -32.

5.4   A calculation of reaction products was made with
the Ruby Code for 2Al-3 aq H_2O_2 (98%).   The code predicted
that 95.5 mole percent of the vapor state charge products
will be steam at the Chapman Jouget pressure (190 kbar
calculated) and that aluminum will be quantitatively oxidized
to Al_2O_3.   In the absence of reducing agents, post-detonation
reactions should be in the direction of steam.   Experimental
results and the Ruby Code concur that detonating 2Al + 3 aq
H_2O_2 (98%) will produce equilibrium reaction products that
are predominantly steam and other condensibles with only
small concentrations of permanent gas.

TABLE 9

Analysis of Aluminum-H_2O_2 Charges With Appreciable Residual Hydrogen

	35/65	38/62	30/70
Weight Ratio Al to H_2O_2	35/65	38/62	30/70
Tetryl (g)	72.0	100.0	100.8
Specific Surface of Al (cm^2/g)	193	386	193
Charge Size (g)	250	277	259

	moles		
Fuel in Charge			
Aluminum	3.22	3.88	2.83
Oxygen equivalent	2.42	2.91	2.12
C and CO	1.76	2.44	2.44
Oxygen equivalent (to CO_2)	1.07	1.48	1.48
O_2 Equivalent total fuel	3.49	4.39	3.60
Oxygen Released by H_2O_2	2.33	2.43	2.59
Al equivalent	3.10	3.24	3.46
Al in charge	3.22	3.88	2.83
Al excess	.12	.64	.00
Al deficiency	.00	.00	.63
Material Balance			
Hydrogen in residue	.96	1.76	.97
Oxygen in residue	.00	.00	.00
Distribution of Released O_2 in Products			
In CO and CO_2	.55	.72	.76
In Al_2O_3	1.78	1.71	1.83
Steam remaining	3.98	3.49	4.65
Aluminum Oxidation			
By steam	.64	1.17	.65
By oxygen directly	2.37	2.28	2.44
Total	3.01	3.45	3.09
Aluminum in Charge	3.22	3.88	2.83
Free Aluminum in residue	.21	.43	.00

TABLE 10

Analysis of Aluminum-H_2O_2 Charges With Little Residual Hydrogen

	A(27/73)	B(27/73)
Weight ratio Al to H_2O_2		
Tetryl (g)	101.2	100.8
Al Specific Surface (cm^2/g)	193	386
Charge Size (g)	284	303

	moles	
Fuel in Charge		
Aluminum	2.82	3.01
Oxygen equivalent	2.12	2.25
C and CO	2.44	2.44
Oxygen equivalent (to CO_2)	1.48	1.48
O_2 Equivalent total fuel	3.60	3.73
Oxygen Released by H_2O_2	2.94	3.10
Al equivalent	3.92	4.19
Al in charge	2.82	3.01
Al excess	.00	.00
Al deficiency	1.10	1.18
Material Balance		
Hydrogen in residue	.15	(-) .02
Oxygen in residue	.00	.00
Distribution of Released Oxygen in Products		
In CO and CO_2	1.02	1.11
In Al_2O_3	1.92	1.99
Steam remaining	6.23	6.86
Aluminum Oxidation		
By steam	.10	.01
By oxygen directly	2.56	2.67
Total	2.66	2.68
Aluminum in Charge	2.82	3.01
Free aluminum in residue	.16	.33

TABLE 11

After Detonation Products of a Charge of Aq. H_2O_2 (97%) Boostered with Tetryl

	Weight (grams)	Molar Quantity (moles)
Tetryl booster	100.48	.35
Charge Composition		
H_2O_2	240.0	7.06
H_2O	10.0	.56
Al(a)	16.5	.61
Detonator	Tetryl 420 mg, lead azide 324 mg	

Composition of Gas Residue

	Detonator & Tetryl Residue (D)	Analysis of Charge Residue (mole %)	Composition of Charge Residue (C) (moles)	C-D (moles)
Hydrogen	.94	0.2	.01	-.93
Nitrogen	.90	19.0	.89	-.01
Carbon dioxide	.19	51.0	2.39	2.20
Carbon monoxide	1.78	0.0	.00	-1.78
Oxygen	.00	29.6	1.51	1.51
Total	3.81	99.8	4.80	

	(moles)
Free oxygen from H_2O_2 decomposition	3.43
Oxygen reacting with tetryl hydrogen	.47
Oxygen reacting with carbon residues	1.31
Free oxygen in products	1.51
Total charge oxygen in the gas residue	3.29
Charge oxygen in condensed products	0.14

(a)   Aluminum tape and foil accessories.

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TABLE 12

Residue from Tetryl and Detonator

Gas Product Composition Based on Nitrogen Remaining and Mass
Spectrometer Gas Residue Analysis

Charge Number	1		2	
Weight of Charge	100.7		101.8	
	(mole %)	(moles)	(mole %)	(moles)
Hydrogen	23.2	.87	25.9	1.00
Nitrogen	23.8	.89	23.3	.90
Carbon Dioxide	4.7	.18	5.0	.19
Carbon Monoxide	48.0	1.80	45.8	1.76
Oxygen	0.1	.00	0.0	.00
Total	99.8	3.74	100.0	3.85

The following average tetryl-detonator residue composition
based on 100 grams of tetryl was used in analyzing aluminum-
hydrogen peroxide and aluminum-lithium perchlorate trihydrate
charge data.

	Moles
Hydrogen	.94
Nitrogen	.90
Carbon Dioxide	.19
Carbon Monoxide	1.78
Oxygen	.00
Total	3.81

TABLE 13

Gas Residue Analysis for 65% Hydrogen Peroxide[a]
35% Aluminum Wool (3 mil filament)

Charge Data	Weight (grams)	Molar Quantity (moles)
Tetryl	72.0	.25
Aluminum	86.7[b]	3.22
H_2O_2	158.2	4.66
H_2O	5.0	.28
Charge Weight	249.9	
Detonator	420 mg tetryl, 324 mg lead azide	

Gas Residue

	Detonator Tetryl Residue (moles)(D)	Charge Residue (mole %)	Charge Residue (moles)(C)	C-D (moles)
Hydrogen	.68	39.9	1.64	.96
Nitrogen	.65	15.8	.65	.00
Carbon Dioxide	.14	21.0	.86	.72
Carbon Monoxide	1.28	22.6	.93	-.35
Oxygen	.00	.0	.00	.00
	2.75	99.3	4.08	

(a) Aq H_2O_2 (97%)

(b) Includes weight of accessory aluminum tape and foil used around charge.

TABLE 14

Gas Residue Analysis for 73% Hydrogen Peroxide[a]
27% Aluminum Wool (1.5 mil filament)
B(27/73)

Charge Data	Weight (grams)	Molar Quantity (moles)
Tetryl	100.8	.29
Aluminum	81.2[b]	3.01
H_2O_2	211.9	6.28
H_2O	10.1	.56
Charge Weight	303.2	
Detonator	420 mg tetryl, 324 mg lead azide	

Gas Residue

	Detonator Tetryl Residue(D) (moles)	Charge Residue (mole%)	Charge Residue(C) (moles)	C-D (moles)
Hydrogen	.94	21.7	.92	-.02
Nitrogen	.90	21.2	.90	.00
Carbon Dioxide	.19	45.8	1.95	1.76
Carbon Monoxide	1.78	11.3	.48	-1.30
Oxygen	.00	.0	.00	.00
	3.81	100.0	4.25	

(a) Aq H_2O_2 (97%)

(b) Including weight of accessory aluminum foil and tape.

TABLE 15

Gas Residue Analysis for 73% Hydrogen Peroxide[a]
27% Aluminum Wool (3 mil filament)
A(27/73)

Charge l ta	Weight (grams)	Molar Amount (moles)
Tetryl	101.2	.35
Aluminum	76.2[b]	2.82
H_2O_2	199.0	5.88
H_2O	9.0	.50
Charge Weight	284.2	
Detonator	420 mg tetryl, 324 mg lead azide	

Gas Residue

	Detonator Tetryl Residue(D) (moles)	Charge Residue (mole %)	Charge Residue(C) (moles)	C-D (moles)
Hydrogen	.95	24.7	1.10	.15
Nitrogen	.91	20.4	.91	.00
Carbon Dioxide	.19	39.7	1.77	1.58
Carbon Monoxide	1.80	15.2	.68	-1.12
Oxygen	.00	.0	.00	.00
	3.85	100.0	4.46	

(a) Aq H_2O_2 (97%)

(b) Including weight of accessory aluminum foil.

TABLE 16

Gas Residue Analysis for 62% Hydrogen Peroxide[a]
38% Aluminum Wool (1.5 mil filament)

Charge Data	Weight (grams)	Molar Amount (moles)
Tetryl	100.0	.35
Aluminum	104.9[b]	3.88
H_2O_2	164.9	4.85
H_2O	7.2	.40
Charge Weight	277.0	
Detonator	420 mg tetryl, 324 mg lead azide	

Gas Residue

	Detonator Tetryl Residue(D) (moles)	Charge Residue (mole %)	Charge Residue(C) (moles)	C-D (moles)
Hydrogen	.94	44.2	2.70	1.76
Nitrogen	.90	14.7	.90	.00
Carbon Dioxide	.19	17.9	1.10	.91
Carbon Monoxide	1.78	23.1	1.41	-.37
Oxygen	.00	.0	.00	.00
	3.81	99.9	6.11	

(a) Aq H_2O_2 (97%)

(b) Including weight of aluminum foil and tape accessories.

TABLE 17

Gas Residue Analysis for 70% Hydrogen Peroxide[a] 30% Aluminum Wool (3 mil filament)

Charge Data	Weight (grams)	Molar Amount (moles)
Tetryl	100.8	.35
Aluminum	76.4[b]	2.83
H_2O_2	175.1	5.18
H_2O	7.9	.44
Charge Weight	259.4	
Detonator	420 mg tetryl and 324 mg lead azide	

Gas Residue

	Detonator Tetryl Residue(D) (moles)	Charge Residue (mole %)	Charge Residue(C) (moles)	C-D (moles)
Hydrogen	.94	36.5	1.91	.97
Nitrogen	.90	17.2	.90	.00
Carbon Dioxide	.19	24.3	1.27	1.08
Carbon Monoxide	1.78	22.0	1.15	-.63
Oxygen	.00	.0	.00	.00
	3.81	100.0	5.23	

(a) Aq H_2O_2 (97%)

(b) Including weight of aluminum tape and foil accessories.

APPENDIX A

Reaction Products for Water Immersed Torpexes

An investigation of the extent of aluminum oxidation in torpex charges (1:1 TNT to RDX, aluminized) is reported in reference 7. The charges were confined in steel shells immersed in a water filled balloon placed in a nitrogen (1 atmosphere) filled calorimeter bomb. As in all charges reported here, oxygen did not appear in any of the gas residues. Table 18 presents oxygen balance and steam reduction data reported in reference 7.

TABLE 18

Hydrogen Produced by Water Immersed Torpexes

Al in Charges (%)	Total Al Oxidized (%)	O.B.(CO)[b] $(gO_2/100g$ Charge)	H.E.[a] Oxygen in Al_2O_3 (%)	Hydrogen in Residue $(gH_2/100g$ charge)
0	0	-12.3	0.0	0.00
15	100	-23.8	41.0	0.00
26	80	-32.2	63.7	0.00
30	82	-35.4	61.5	0.89
40	81	-43.0	50.0	2.44
50	80	-50.7	34.2	7.45

(a) High Explosive Matrix

(b) Oxygen balance based on CO and Al_2O_3

Though Table 18 shows no hydrogen produced at O.B. -32.2 gO_2/
100g charge, this is the point (26% aluminum in the charge)
after which steam reduction begins and increases with higher
aluminum concentrations and lower oxygen balances. Torpexes
can be prevented from reducing environmental water by keeping
the O.B. above -32.2, equivalent to maintaining aluminum in
the charge below 26%. Reference 7 demonstrates that a) the
matrix oxygen in torpexes reacts completely with available
fuel, b) at O.B.'s above -32.2 reduction of water su ounding
the charge does not occur and c) torpexes having O.B. s of
-23.8 and above oxidize the charge aluminum completely.

APPENDIX B

Illustrative Calculations

1. Calculation of Composition Based on Pressure Rise in Detonation Tank and Mass Spectrometer Analysis.

Charge	101.83 g Tetryl
Initiator	324 mg lead azide
	420 mg tetryl
Tank Pressure before shot, P_1	38.0 mm Hg.
Tank Pressure after shot, P_2	802.0 mm Hg.
$P_2 - P_1 = P$	764.0 mm Hg.
Equilibrium Temperature after shot	26.0°C (299.2°K)
Molar gas constant, R	.0821 liter atmospheres/°C
Volume of tank	103.16 liters
Moles of gas, N in tank after shot (from gas law)	4.28 moles

	Gas Analysis (mole %)	Total Gas (moles)		Constituent Quantity (moles)
Hydrogen	2ɔ.2 x	4.28	=	1.00
Nitrogen	23.8 x	4.28	=	1.02
Carbon Dioxide	4.7 x	4.28	=	.20
Carbon Monoxide	48.0 x	4.28	=	2.06
Oxygen	0.1 x	4.28	=	.00
	99.8			4.28

2. Calculation of Composition Based on Known Concentration of Nitrogen in the Detonation Tank After the Shot.

(Moles)

Nitrogen in tetryl
  (charge and detonator)   .882
Nitrogen in lead azide   .003
Total nitrogen   .885 ($\sim$.89)

	Mole %	Quantity (moles)
Hydrogen	23.2	.87
Nitrogen	23.8	.89
Carbon Dioxide	4.7	.18
Carbon Monoxide	48.0	1.80
Oxygen	0.1	.00
	99.8	3.74

     Molar composition of the residue gas could be calculated
in two ways. In the first, the permanent pressure rise in
the tank was used to find the moles of gas produced. Final
pressures were between 1 and 2 atmospheres so that the ideal
gas law gave a close approximation of the number of moles
present. Concentrations of individual components were then
found by multiplying the total number of moles of gas by mole
percentages from the mass spectrometer analysis.

     In the second method which was used in the charge studies,
concentrations were calculated from the known amount of nitrogen
injected into the gas residue by the tetryl and detonator.
This together with the mole percentage of nitrogen in the
residue found by analysis made it possible to calculate
concentrations of the other gas components. Mole concentrations
based on the gas law are higher by about 10% than those
calculated from the nitrogen level. This is attributed
to gas law deviation and to accuracy limitations in the pressure-
temperature measurements. Data used in analysis of the
aluminum-hydrogen peroxide charges are based on concentration
differentials between products of the booster and tetryl alone
and with the charge. Absolute accuracy is therefore less
important than precision. The mass spectrometer analyses are
accurate to within $\pm$ 1%. Pressures under atmospheric were
measured with a mercury manometer calibrated in tenths of an
inch. Static after-detonation pressures were read on a
calibrated Hoke Bourdon-tube gauge (0.2 pound calibrations)
and a diaphragm absolute-pressure gauge (2 mm of mercury
calibrations). The temperature was least precisely known
since the gas temperature at the pressure measurement was taken
as the time-lapse equilibrium tank temperature.

APPENDIX C

Packaging of an Aluminum-Hydrogen Peroxide Charge

In the preparation of larger aluminum-hydrogen peroxide charges for underwater testing, a container must be employed meeting the following principal requirements, (a) compatibility with concentrated H_2O_2, (b) sufficient strength when loaded with aluminum fuel to support evacuation during injection of H_2O_2, and (c) spherical shape. A strong, rigid tank may impede energy transfer from charge to water. A semi-rigid aluminum sphere partially supported by the aluminum fuel is proposed as having the best combination of properties. Water buoyancy and rigidity of the aluminum charge inside the sphere may provide sufficient support for the submerged or partially submerged tank during evacuation and injection of the oxidant. Figure 1 is a sketch of a tank of this type. The structural material can be 99.6% (minimum) aluminum which is commercially available at reasonable prices. Structural failure of the charge holder when completely loaded will not have disastrous effects in a large mass of water. Water dilutes the H_2O_2 to harmless levels without chemical reaction. Dilution evolves heat but if the surrounding water mass is large, temperatures will remain low.

A homogeneous charge is important for complete detonation and minimum steam reduction. There may be technical difficulties in preparing homogeneous large scale charges with pressed aluminum filament. Another means of dispersing aluminum is the employment of aluminum spinel having a length and diameter producing the required packing density. The surface area of the spinel must be large enough for complete combustion. Neither the spherical tank nor this method of charge preparation have been investigated experimentally but are believed to be the best initial approach to the preparation of larger charges.

Acknowledgements
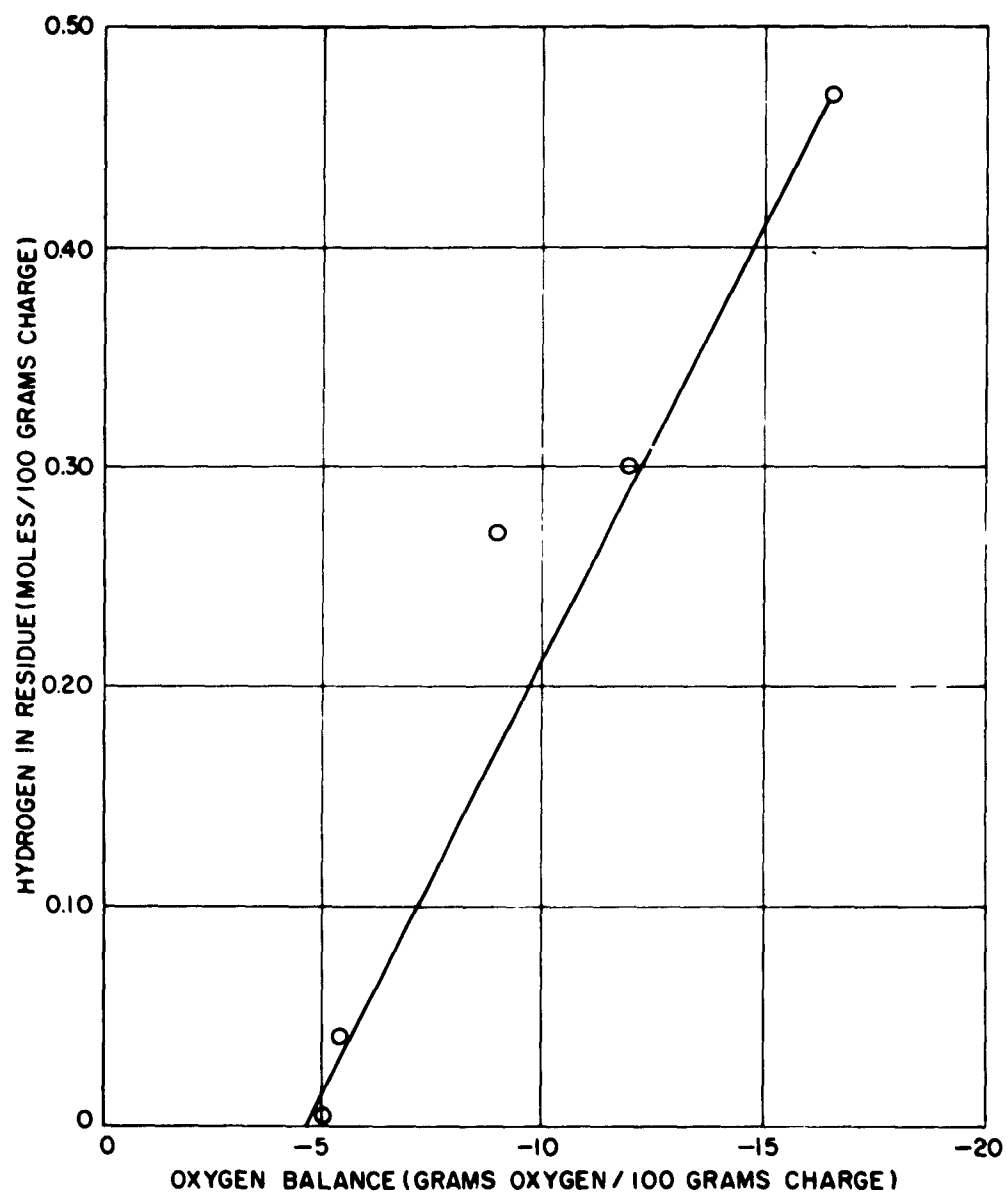
FIG. I RESIDUE HYDROGEN VS OXYGEN BALANCE
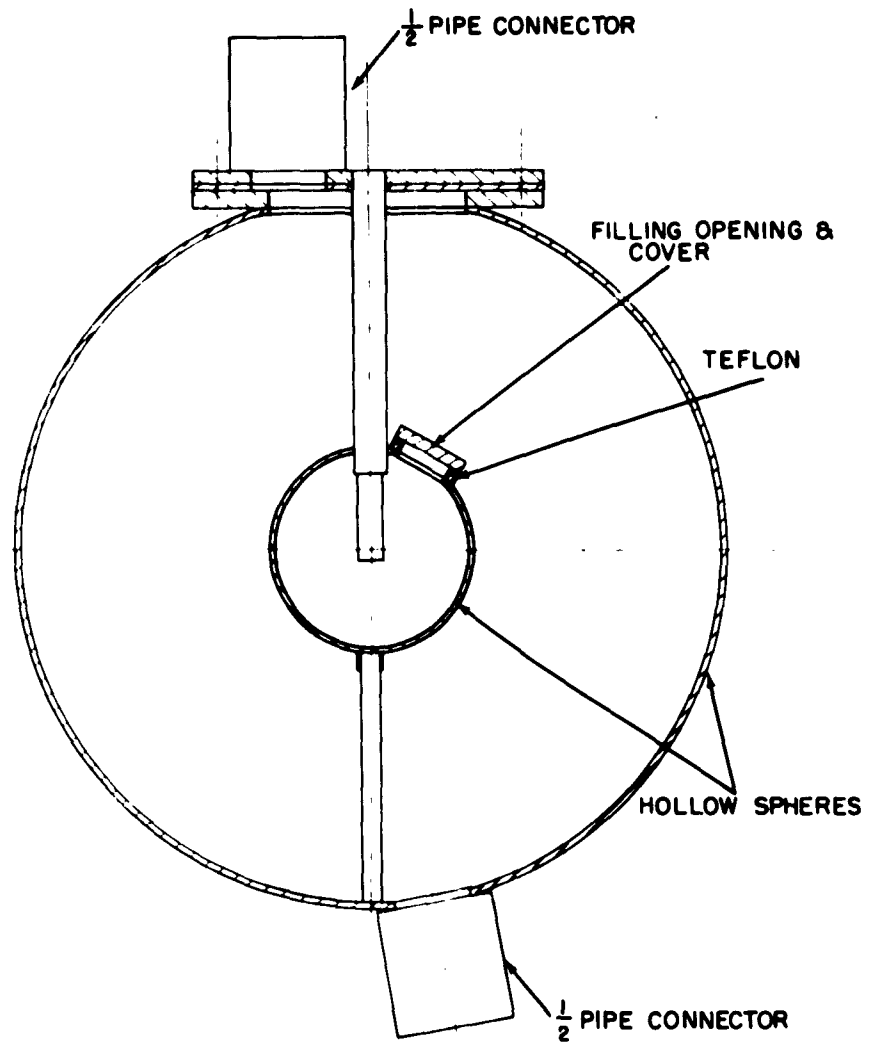
FIG. 2 PROPOSED IOLB SPHERICAL CHARGE

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DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Explosives	EXP?	Addition	?C??	Comparison	EXPR
Generating	GEN?	Perchlorate	PER?	Experiment	EXPE
Condensible	COD?	Trinitrate	?R??	Ring code	RBYC
Products	PRO?	Measurement	MEA?	Calculations	CONA
Reaction	REA?	Rates	RA??	Water	WATR
Compositions	CMP?	Confined	CA?	Immersed	?N??
Detonation	DET?	Charges	HAR	Torpex	TORE
Velocities	VEL?	Balances	BAL?	Gap test	GAPT
Equilibrium	EQUL	Oxide	OXID	Sensitivity	SENV
Aluminum	ALM?	Steam	STEA	Amorphous	AMOR
Hydrogen	HYDG	Concentration	CNCT	Powder	POWD
Peroxide	PERO	Oxygen	OXYG	Stability	STBI

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-12)
TWO EXPLOSIVES GENERATING CONDENSIBLE PRO-
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illus., tables. BuWeps task RUOI-RA932/212-9/
F008-21-003-000.   UNCLASSIFIED
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various negative oxygen balances were analyzed
Hydrogen concentrations diminished with rising
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action products are in agreement with experi-
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